# CHEMICAL SOLIDIFICATION OF SOIL IN TUNNELING AT A MINNESOTA IRON-ORE MINE

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# CHEMICAL SOLIDIFICATION OF SOIL IN TUNNELING AT A MINNESOTA IRON-ORE MINE[1]

by

R. O. Pynnonen[2] and Allen D. Look[3]

## SUMMARY AND INTRODUCTION

Tunnel-driving is recognized as a hazardous occupation; adequate support of roof and sides for preventing accidents from falling material is usually one of the most important safety problems. Where extraordinary conditions of sand and water are found, this problem becomes even more difficult.

Tunneling at the Tioga No. 2 mine was stopped when a 22-foot bed of water-saturated, fine gray sand was encountered. The tunnel, designed to house an ore-conveyor belt, was being driven from both ends. Driving was extremely difficult at both the upper and lower faces when the sand horizon was reached. A distance of 178 feet remained between the faces. Heavy pressures deformed the steel-supporting rings at the upper face, and there was an inrush of mud and sand at the lower face.

All efforts to advance the faces failed. Conventional methods of stabilization, including the use of about 650 bags of cement in grouting, were unsuccessful. Little consolidation resulted, and much of the grout was forced to some unknown place.

The tunnel was completed finally by chemical soil stabilization. Solutions of sodium silicate and calcium chloride were forced into the water-bearing sand, consolidating the sand and removing the problem of water. Excavating was done with pneumatic spades.

This paper does not attempt to compare the costs of various methods of ground support. The process described was a comparatively safe method of completing the tunnel at the Tioga No. 2 mine after dangerous conditions had developed under conventional mining methods.

## ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance of Frank Werther, operating assistant, Pickands Mather & Co., Duluth, Minn., who supplied photographs, sketches, and a description of the company experience with this method. Acknowledgment also is made to A. Anderson, superintendent of the Tioga No. 2 mine and C. Martin Riedel, civil engineer and president, Chemical Soil Solidification Co., Inc., for information and assistance.

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## GENERAL INFORMATION

The Tioga No. 2 open-pit was mined for iron ore by Pickands Mather & Co. in Itasca County, 5 1/2 miles southwest of Grand Rapids, Minn. The property is bounded on the east by Pokegama Lake and on the south by Cavanaugh Lake. Production from the mine was begun in 1955; 564,517 long tons of ore was shipped in 1956. The ore is low grade and is concentrated either by washing or by heavy medium methods.

Ore was loaded into trucks by electric shovels, hauled to a pocket at the bottom of the pit, and passed over a screen; the oversize ore was crushed and carried with the undersize ore to the mill by a single-flight belt conveyor.

During development of the mine, the best method of bringing the belt out of the pit was given considerable thought, resulting in installation of the belt in a tunnel driven into the pit bank.

### Planning

The decision to drive a tunnel through the pit bank was made with the realization that a fine gray-sand horizon could present a problem if water was found. Overburden consisted of 22 feet of clay and gravel, 15 feet of gray marl, 35 feet of yellow sand, 25 feet of marl, 22 feet of fine gray sand, and 81 feet of marl. The fine gray sand horizon had presented difficulties during stripping, which had drained the immediate area; but before the final decision, two test holes were drilled along the line of the proposed tunnel. Little evidence of water was found in the test holes.

Final plans included a 2,265-foot conveyor flight with a total lift of 254 feet. The 9-foot-diameter, circular tunnel section was 972 feet long and inclined about 12°. Steel liner plates, 16 inches wide, 9 plates to a ring, were used for support.

### Early Operations

Excavation of the tunnel was begun at both the upper and lower ends, and three-man crews were employed at both faces. Holes were drilled in the marl formation with percussion machines and auger bits. Just enough explosives were loaded in the 4-foot holes to shake up the ground. The cut was completed with pneumatic clay spades, and the dirt was removed from the tunnel with scrapers pulled by electrically powered tuggers.

Difficulties were not experienced in the marl formation, but progress was soon halted when the fine gray sands were encountered. Conventional methods of advance failed, and the tunnel section near the face in the upper heading began to take weight, resulting in deformation of the steel rings.

In an attempt to stabilize the ground, grouting was begun outby the damaged section of the tunnel. The grout was pumped through holes cut in the steel liner plates to form a complete seal around the tunnel. This procedure was followed until the seal was completed to the tunnel face.

Attempts to grout the strata in advance of the tunnel through pipes in the face and from surface failed. Little or no grout could be forced through the face pipes, and the grout injected through the surface pipes disappeared to some unknown area. After a run of wet mud and sand occurred at the face of the lower heading, the grouting was discontinued, and a chemical soil-solidification company was engaged to stabilize the sand in the path of the tunnel excavation.

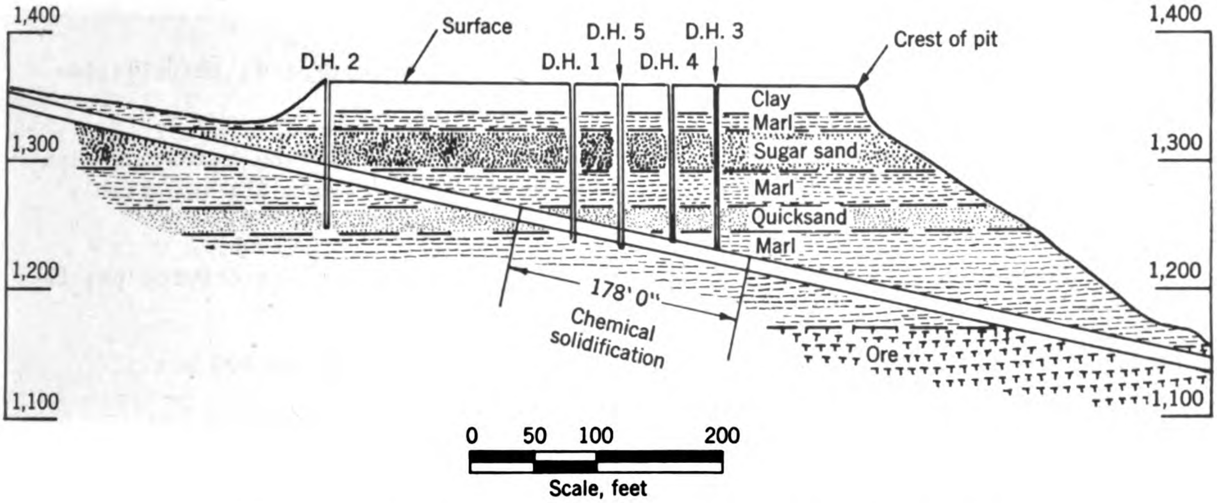

FIGURE 1. - Section of Tunnel Showing Area Chemically Solidified.

## JOOSTEN PROCESS

### Theory

The Joosten process is a method of chemically solidifying loose sands and soils that are permeable to water. The process was invented by a Netherland mining engineer, Hugo J. Joosten, following his success in sealing salt-mine shafts against water inflow by injecting sodium silicate solutions into the strata. Laboratory tests showed that sand particles were cemented when mixed with a highly concentrated solution of sodium silicate and a strong saline solution.

The purpose of the Joosten process is to solidify and seal strata of loose sand permeable to water and such other structures as are porous and subject to decomposition. The process consists of consecutive injection of two solutions, which will instantly bring about precipitation of silicic gel. Essentially, the first solution is an almost saturated solution of sodium silicate (waterglass) and the second a strong saline solution, such as calcium chloride. The chemical reaction of the solutions within the treated mass results in the precipitation of a silicic gel, which coats the individual sand particles with a thin film having high surface tension. Thus the separate particles of the treated mass are cemented, and as the gel fills the spaces between particles, sealing is effected. Excess water is pushed beyond the solidifying range owing to additional pressure as cementation continues.4/

Some of the advantages claimed for the Joosten process are: There is immediate solidification with no setting time required; there is no dilution of the chemical solutions by ground waters; solidification is independent of the nature of the soil and little affected by the chemical properties; few items of equipment are needed; and the method can be used for underground work. The process uses true solutions which penetrate small-pored and fine-fissured material that would filter out cement in suspension.

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4/ Joosten, H. J., The Joosten Process for Chemical Soil Solidification and Sealing and its Development From 1925 to Date: Van Waesberge, Hoogewerff & Richardson, N. V., Rotterdam, pp. 1, 2.

## Equipment and Crew Needed

The amount of equipment needed is not excessive, and a typical installation generally is listed as follows:

(1) Injection pipes similar to well points. Special driving heads and pipe connections designed to stand punishment are needed when driving through highly packed soil or withdrawing from the solidified area at great depths.

(2) Compressed-air hammer and drop hammer or pipe pusher for driving the injection pipes

(3) Double-acting chemical pumps to provide pressures up to 400 p.s.i.

(4) Pressure hose with attachments of a type that will permit quick disconnection.

(5) Suction tanks.

(6) Paddle-type mixing outfit for mixing chemical No. 2 (usually calcium chloride) at the site.

(7) Heavy twin hydraulic jacks for withdrawing pipes from injection area.

(8) Miscellaneous pipefitters' tools.

A supply of water for mixing of the chemicals and flushing pipes and a source of compressed air at 100 p.s.i. are required.

A crew of 1 experienced foreman, 1 pump operator, 1 pipe keyman, and 2 laborers is usually enough to handle the actual injection work at 1 tunnel face. The foreman and pump operator should be thoroughly familiar with the chemical-injection equipment, but labor can be hired locally. On larger jobs 3 injection crews or more can handle 1 compressor and mixing plant.

## Application at Tioga No. 2 Mine

Chemical solidification of the sands was begun at the upper heading. The solutions of sodium silicate and calcium chloride were prepared at the tunnel entrance. Compressed-air pumps, attached to the solution tanks, forced the solutions to the tunnel heading through 1-inch-diameter lines. The injection pipes were made from A-section diamond-drill rods. A special spear-shaped driving head was used with the rods. Driving was accomplished with pneumatic hammers, and the pipes were withdrawn from the holes with hydraulic jacks. A communication system was set up to permit conversation between the face and the pump station.

Three series of pipes were driven at the face for introducing the chemicals. One series was driven around the circumference of the tunnel just back of the existing face to a depth of 3 feet. A second series was driven ahead of the face and flared to the sides to solidify a section in the form of a truncated cone. A third series of pipes was driven ahead of the tunnel and in the line of advance to a distance of 8 feet. This pattern gave a solidified area large enough to permit a safe tunnel advance of 6 to 10 feet with a 2-foot thickness of firm ground left in the face.

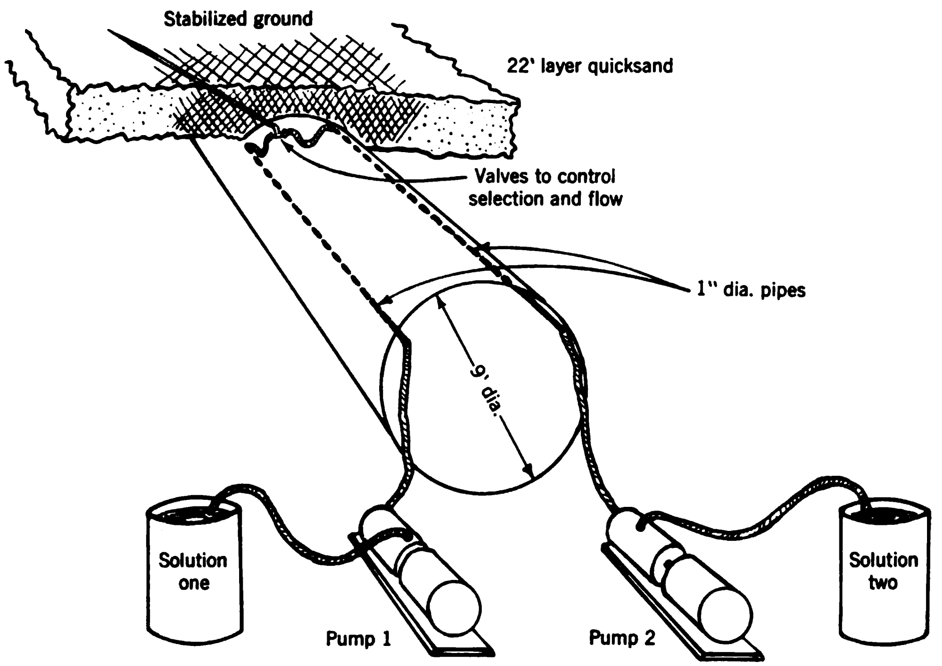

FIGURE 2. - Schematic Hookup of Injection Equipment.

After the pipes were driven to the desired depth, a specified quantity of sodium silicate solution was injected under pressure. This forced out and replaced the water in the immediate area. The pipes were then flushed sparingly with water, and the calcium chloride solution was injected. Pipes were then withdrawn 1 foot, and the cycle of injections of sodium silicate and calcium chloride solutions was repeated. This process was repeated until the pipes were withdrawn from the holes.

In any particular job of chemical soil solidification the pattern and spacing of pipes, injection pressures, and viscosity of solutions will be varied by an experienced engineer to fit the conditions. Determination of grain size, permeability of the mass to be treated, and laboratory solidification tests of representative soil samples to determine proper mixtures are essential to proper planning.

The nature of the two solutions permits penetration into fine pores, and tests have shown that the saline solution will penetrate any strata reached by the sodium silicate. A precipitated silicic gel cements the sand grains to form a stable stratum.

After a section had been stabilized, tunnel crews advanced the face 6 to 8 feet, leaving a 2-foot-thick plug of firm ground in advance of the face. The material was excavated easily with the pneumatic clay spades, and no blasting was necessary. Stabilization and excavation were repeated until the quicksand area in the upper tube was passed, and normal tunneling was resumed.

The stabilizing crew began work at the lower face after it was possible to resume the normal tunneling in the upper tube. It was first necessary to repair a 14-foot section of the tunnel where a "mud run" and the resultant pressures had badly damaged the steel lining. As the ground around the damaged section was stabilized, damaged liner plates were removed and replaced. The face area was then stabilized

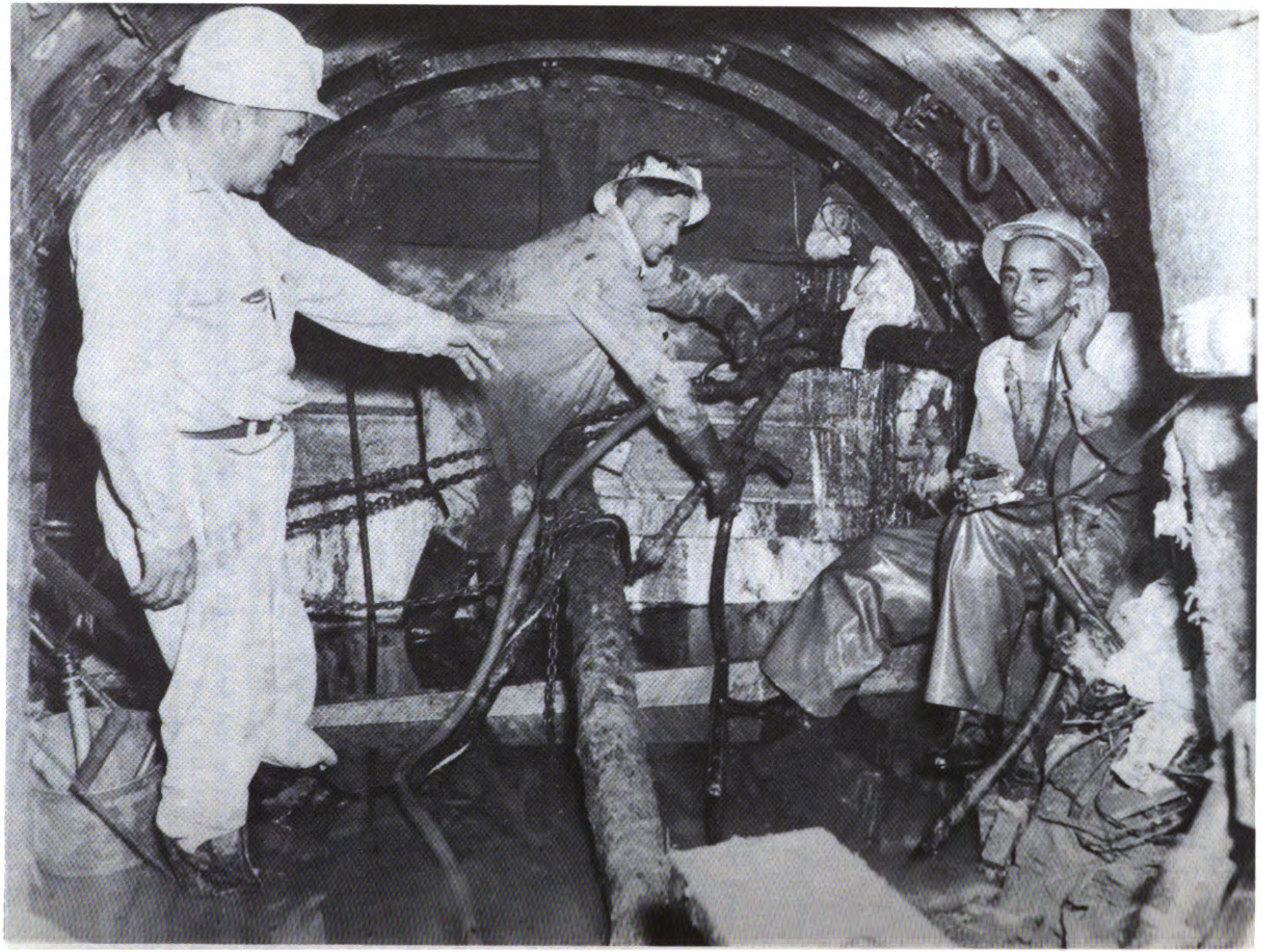

FIGURE 3. - Chemical Injection at Tunnel Face Showing Face Crew, Injection Pipe, and Chemical Hoses.
*(Courtesy, Grand Rapids Herald-Review.)*

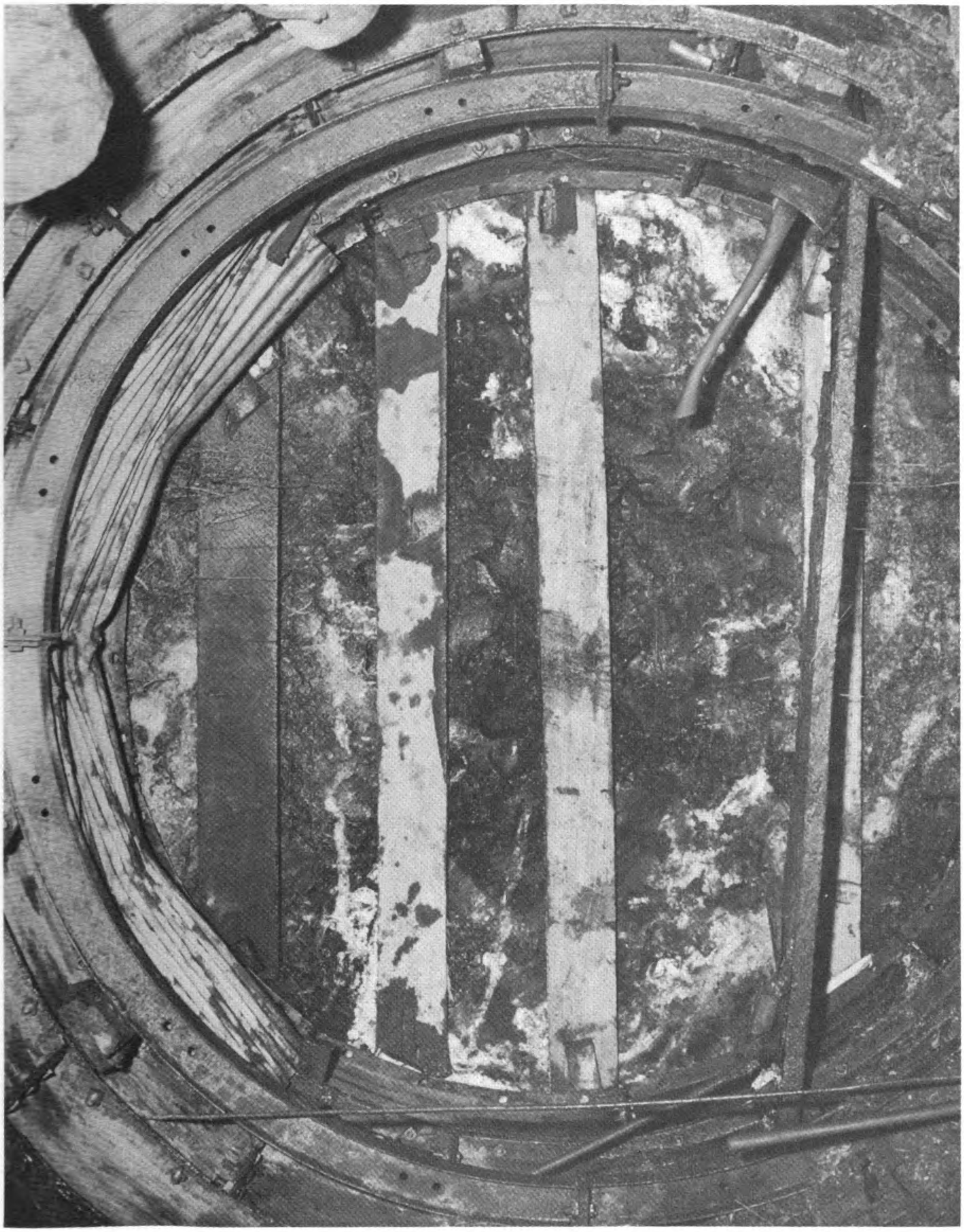

FIGURE 4. - Face of Tunnel Showing Solid Nature of Previously Unstable Quicksand After Chemical Injections.
*(Courtesy, Chemical Soil Solidification Company.)*

by repeating the cycle of injection stages and the two headings met, holing through a plug of stabilized ground.

## CONCLUSION

The difficult tunneling at Tioga No. 2 mine was completed through the use of chemical soil solidification after grouting failed to solve the problem. Chemical soil solidification is not a cure-all for all stabilization problems, since clays and fine silts cannot be stabilized as yet. Where rapidly flowing ground waters are present, special precautions must be taken to prevent the chemicals from being carried off before becoming effective. In areas containing large crevices or voids, the cost may become prohibitive. The inventor recommends cement grounting of the larger crevices first, followed by chemical solidification in such areas. Careful planning, including preliminary laboratory tests, and experienced supervision are recommended for satisfactory results.

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